

Numerical Modeling of Nonlinear Baroclinic Fluid Systems

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In developing a comprehension of the processes that affect global change on Earth, a component that presents one of the greatest challenges is that of the fluid system composed of the atmosphere and oceans. Clearly, a broader understanding of this system is an important one, since the atmosphere is the fluid system in which we live—the system that supplies the land with fresh water and shields life from harmful solar radiation. The oceans interact with the atmosphere through exchanges of heat, water, and momentum and provide a very large “thermal mass” for the system. Due to the complex nature of this system and the difficulty in obtaining sufficient observational data on it, accurately predicting its behavior for all but very short time periods remains an elusive goal. The aim of this research is to develop a better understanding of the Earth system through the use of various computer models to allow the study of the atmosphere, as well as the complicated behavior of a rather simple fluid system driven by horizontal temperature gradients and influenced by rotation.

One means of investigating the behavior of the Earth’s atmosphere and oceans is to conduct laboratory experiments in cylindrical and spherical containers where a fluid such as water is differentially heated and rotated. Depending upon the strength

of the differential heating and the rate of rotation, the flow may be very simple—steady in time and axisymmetric in structure. For other values of the heating and rotation, the flow may be made of steady, regular waves, or it may be quite irregular and chaotic. Such experiments have been conducted in laboratories, both at MSFC and elsewhere, resulting in a numerical model developed at MSFC that tests our ability to predict flow types and to assist in comprehending such processes as heat and momentum transport. Additionally, studies are being performed to help design space-flight experiments using the geophysical fluid-flow cell apparatus.

The Geophysical Fluid-Flow Simulator enables scientists to experiment with both spherical or cylindrical flows. Flow analysis proceeds in several steps: calculation of the axisymmetric flow (that which would be seen if no variations in longitude are allowed); calculation of the linear stability of that flow to three-dimensional wave perturbations; calculation of the wave amplitude where interaction between the wave and the longitudinal mean flow is allowed; and the calculation of the fully nonlinear flow with full interaction between all components of the flow. The extent to which each of these steps can be directly applied to the actual flows depends upon the nonlinearity of the flow, which, in turn, depends upon the experimental parameters. For highly nonlinear flows, a time series of images of the predicted flow are produced; the images are shown in computer animations to illustrate the interactions between various types of structures in the flow.

Recent work has placed emphasis on vacillatory flow in the baroclinic annulus experiments. The flow occurring in the gap between two concentric, co-rotating cylinders that are differentially heated is computed with high resolution and for (typically) several tens of rotational periods. For certain combinations of rotation rates and temperature differences, the resulting flow is three-dimensional and undergoes a periodic oscillation in the amplitude of the “wave” part of the structure. Agreement between the computer simulations and previous laboratory experiments is very good. The computer calculations allow the investigation of more cases than has been done experimentally. This work has resulted in the demonstration that a numerical model can be used to identify deterministically predictable regions in parameter space, as opposed to regions in which the result is highly sensitive to numerical and physical parameters. An investigation into the mechanics of the various flow regimes is continuing.

Lu, H.-I.; Miller, T.L.; and Butler, K.A. 1994. A Numerical Study of Wave-Number Selection in the Baroclinic Annulus Flow System. *Geophysical and Astrophysical Fluid Dynamics*, 75:1–19.

Sponsor: Office of Mission to Planet Earth

